

1996 NASA AEROSPACE BATTERY WORKSHOP

NiH₂ BATTERY RECONDITIONING FOR LEO APPLICATIONS

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ABSTRACT

This paper summarizes reasons for and benefits of reconditioning nickel-hydrogen (NiH₂) batteries used for Low Earth Orbit (LEO) applications. NiH₂ battery cells do not have the classic discharge voltage problems more commonly associated with nickel-cadmium (NiCd) cells. This is due, in part, to use of hydrogen electrodes in place of cadmium electrodes. The nickel electrode, however, does have a similar discharge voltage signature for both cell designs. This can have an impact on LEO applications where peak loads at higher relative depths of discharge can impact operations. Periodic reconditioning provides information which can be used for analyzing long term performance trends to predict usable capacity to a specified voltage level. The reconditioning process described herein involves discharging NiH₂ batteries at C/20 rates or less, to an average cell voltage of 1.0 volts or less. Recharge is performed at nominal C/5 rates to specified voltage/temperature (V/T) charge levels selected to restore required capacity with minimal overcharge. Reconditioning is a process of restoring reserve capacity lost on cycling, which is commonly called the memory effect in NiCd cells. This effect is characterized by decreases in the discharge voltage curve with operational life and cycling. The end effect of reconditioning NiH₂ cells may be hidden in the versatility of that design over the NiCd cell design and its associated negative electrode fading problem. The process of deep discharge at lower rates by way of reconditioning tends to redistribute electrolyte and water in the NiH₂ cell electrode stack, while improving utilization and charge efficiency. NiH₂ battery reconditioning effects on life are considered beneficial and may, in fact, extend life based on NiCd experience. In any case, usable capacity data obtained from reconditioning is required for performance evaluation and trend analysis. Characterization and life tests have provided the historical data

base used to determine the need for reconditioning in most battery applications. The following sections briefly describe the background of NiH₂ battery reconditioning and testing at Lockheed Martin Missiles & Space (LMMS) and other aerospace companies.

BATTERY RECONDITIONING BACKGROUND

Reconditioning is a discharge-charge sequence normally applied to NiCd batteries to minimize degradation of the battery electrical performance, specifically capacity measured to a nominal voltage of 1.1 volts per cell. The process involves discharge of the battery at C/20 rates or less, to an average cell voltage of 1.0 volts or less. The subsequent charging process must be sufficient to restore rated, or actual measured capacity, whichever is greater, in order to compensate for charge efficiency. Reconditioning is a process of restoring reserve capacity lost on cycling, which is commonly called the memory effect in NiCd cells. It is characterized by decreases in the voltage of the discharge curve with operational life and cycling. Although NiH₂ battery cells do not have the classic voltage degradation problems that NiCd cells have, the nickel electrode has a similar discharge voltage signature during cycling for both cell designs. The effects of reconditioning on NiH₂ cells may be hidden in the versatility of that system over the NiCd system and its associated negative electrode fading problem. Water loss from the electrode stack can occur in NiH₂ cells by evaporation from the stack and condensation at the pressure vessel wall. This is normally compensated for in MANTECH NiH₂ cell designs by a wall wick inside the pressure vessel which returns any electrolyte loss or water loss from the stack by way of the separator in contact with the wall wick. COMSAT cell designs do not have a wall wick and therefore are more subject to adverse effects of electrolyte loss or water loss from the cell stack. Such losses are usually encountered during cell overcharge, which must be minimized in COMSAT battery cells. Hydrogen gas is oxidized to water during discharge and reformed to gas during charge for both COMSAT and MANTECH NiH₂ cell designs. COMSAT cell designs have teflonated pressure vessel walls that are not hydroscopic which tends to repel any water loss from the stack back into the stack in a zero G environment. The process of deep discharge by way of reconditioning tends to redistribute electrolyte and water in the cell stack, and improve utilization and charge efficiency. Reconditioning effects on life are considered beneficial and may, in fact, extend life based on NiCd experience. In any case, the capacity data

obtained from reconditioning can be used for performance evaluation and trend analysis. This has been documented in Reference (1) for GEO applications for COMSAT cell designs. In-orbit performance of batteries is normally judged by the minimum end-of-discharge voltage (EODV) during peak loading. GEO batteries are usually reconditioned prior to each eclipse season to verify capacity to an end voltage. LEO batteries are reconditioned as required to verify long term capacity fading trends such as described for HST MANTECH NiH₂ batteries in Reference (2). Capacity tests at nominal reconditioning rates have shown a trend of decreasing capacity with cycle life for the HST mission. Extrapolation of that data has provided a basis for determining the useful life of the HST batteries beyond the specified design life of seven years. Recondition discharge of the HST batteries is performed through a 25 ohm resistor to an end voltage of 15 volts (0.7 volts per cell). This voltage limit minimizes the potential for cell reversal at end of discharge when actual discharge rates approach a C/150 rate. It also allows for more complete redistribution of electrolyte for improved utilization and charge efficiency. The following section summarizes testing background which has provided the historical data base for determining the need for reconditioning NiH₂ batteries.

BATTERY TESTING BACKGROUND

Battery test facilities for characterizing and life testing cells and batteries exist at most aerospace companies. TRW's battery test facilities were established in the 1960's following battery problems associated with various NASA programs. TRW performed extensive characterization tests for NASA on NiCd cells in the 1960's and 1970's as documented in Reference (3). GSFC began characterization testing of various cell and battery designs at NWSC in Crane, Indiana, during the same time period. Ford Aerospace Company (now Loral) and Hughes Aircraft Company (HAC) established battery test facilities in the 1970's for the Intelsat IV, V and VI satellite programs. Martin Marietta, GE Valley Forge and RCA battery test facilities were also established in the same time period for other military and commercial satellite applications utilizing NiH₂ batteries. Development and test history for these and other NiH₂ designs are documented in Reference (1). As NiH₂ and other advanced battery designs have been integrated into more sophisticated spacecraft programs at LMMS (HST, Milstar and Iridium), increased battery test costs have forced descoping of tests to reduce costs. The trend to reduce overhead

costs of long term battery and cell performance characterization testing by descoping tests requires some risk assessment analysis. Battery problems usually drive the need for more extensive development and test programs, such as happened in the 1960's when battery failures affected end item operations, as documented in Reference (4) for the Orbiting Astronomical Observatory (OAO) satellite. Batteries normally fail gracefully and in a predictable manner which can be reliably quantified based on a relatively large test data base as reported in Reference (5). The need to maintain battery test facilities can only be determined by an assessment of whether or not the existing data base can be used to predict battery life for particular spacecraft power requirements. The following section summarizes results of NiH₂ battery life testing for a specific LEO application which uses reconditioning to predict usable capacity to a specified voltage level.

BATTERY RECONDITIONING

A series of tests were initiated at Eagle Picher Industries (EPI) to evaluate effects of reconditioning on long term performance of RNH-76-3 NiH₂ cells. The testing consisted of cycling at 41°F to a maximum depth-of-discharge (DOD) of 33 Ah. Test articles included a 9-cell pack and a 20-cell battery. The objective of the 9-cell pack reconditioning test was to evaluate the reconditioning effectiveness for a battery configuration between a 25 ohm discharge to 15V and a 5.3 ohm discharge to 25V, then 25 ohm to 15V. The following tests were completed on the 9-cell pack:

<u>TASK NUMBER</u>	<u>RECONDITION RATE</u>
4A	2.2 Ohm to 6.14V
4B	2.2 Ohm to 6.14V
4C	2.2 Ohm to 10.64 V
	10.2 Ohm to 6.14V
4D	2.2 Ohm to 10.64V
	10.2 Ohm to 6.14V

The actual recondition discharge tests performed did not significantly change the discharge voltage stabilization levels for Tasks 4A, 4B or 4C as shown in Figure 1. However, a significant improvement in the discharge voltage level occurred during performance of Task 4D following one week of discharged open circuit stand after reconditioning, also shown in Figure 2. A reconditioning sequence designated D2 was then performed according to the same test procedure as the reconditionings for Tasks 4C and 4D. The comparison of reconditionings D and D2 plotted in Figure 3 show very stable voltage performance to 10.64V. The reduced capacity after removal of approximately 86Ah was due to lower capacity of one cell in the pack during the D2 reconditioning discharge. The significant voltage improvement during performance of Task 4D was attributed to redistribution of electrolyte and water in the cell electrode stack following one week open circuit stand after reconditioning at the lower discharge rate (10.2 Ohm to 6.14V).

The objective of the 20-cell battery test was to verify long term battery performance under similar test conditions as imposed on the 9-cell pack. Figure 4 illustrates improvements in minimum daily voltages after 12,000 cycles following capacity checks or partial reconditionings. The capacity checks consisted of discharging at 15A to 13.6V, or until the first cell reached 0.7V. Figure 5 shows voltage performance versus cycles experienced since reconditioning events shown in Figure 4. A trend in decreasing EODV with cycle life similar to the 9-cell pack test was observed for the battery test. The following section summarizes conclusions reached from analysis of data presented herein.

CONCLUSIONS

The end effect of reconditioning NiH₂ cells provides usable capacity data for performance evaluation and trend analysis. NiH₂ battery reconditioning effects on life are considered beneficial and may, in fact, extend life based on NiCd experience. Characterization and life testing have provided a historical data base to determine the need for reconditioning to improve voltage performance to a specified voltage level. Although NiH₂ battery cells do not have the classic voltage degradation problems that NiCd cells have, the nickel electrode has a similar discharge voltage signature during cycling for both cell designs. The process of deep discharge by way of reconditioning tends to redistribute electrolyte and water in the NiH₂ cell stack, and

improve utilization and charge efficiency. In-orbit performance of batteries is normally judged by the minimum EODV reached during peak loading. GEO batteries are usually reconditioned prior to each eclipse season to improve voltage performance and verify capacity to an end voltage. LEO batteries are reconditioned as required to verify long term capacity fading trends such as summarized herein. Extrapolation of reconditioning discharge data provides a basis for predicting cycle life performance for both NiCd and NiH₂ batteries.

REFERENCES

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5. D.P. Hafen, **Comparison of Nickel-Hydrogen and Nickel-Cadmium Reliability**, IECEC Paper 929257, August 1992.



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Presented at

**The 1996 NASA Aerospace Battery Workshop
Focused Session on NiH₂ Battery On-Orbit Reconditioning Experience**

December 3, 1996



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NiH₂ Battery Reconditioning in LEO

OBJECTIVE

- RESTORE RESERVE CAPACITY LOST ON CYCLING
- IMPROVE VOLTAGE PERFORMANCE AND CYCLE LIFE
- REDISTRIBUTE ELECTROLYTE AND WATER IN CELL STACKS
- IMPROVE ELECTRODE UTILIZATION AND CHARGE EFFICIENCY
- ESTABLISH DATA BASE FOR LONG TERM PERFORMANCE EVALUATION



NiH₂ Battery Reconditioning in LEO

PROCEDURE

- DISCHARGE AT C/20 OR LESS TO 1.14 V/CELL NOMINAL
- DISCHARGE AT C/100 OR LESS TO 0.7 V/CELL NOMINAL
- RECHARGE AT C/5 TO TEMPERATURE-COMPENSATED VOLTAGE LIMIT
- REPEAT AS NECESSARY TO STABILIZE CELL CAPACITY AND VOLTAGE
- COLLECT DATA FOR PERFORMANCE EVALUATION AND TREND ANALYSIS



NiH₂ Battery Reconditioning in LEO

LIFE TESTING

- SERIES OF TESTS CONDUCTED TO EVALUATE EFFECTS OF RECONDITIONING
- TEST ARTICLES INCLUDED 9-CELL PACK AND 20-CELL BATTERY
- TEST CONDITIONS BASED ON 90 Ah NOMINAL CAPACITY
 - 96 MINUTE CYCLING AT 41°F (5°C)
 - 33 Ah MAXIMUM DOD ONCE PER DAY
 - 15 A NOMINAL LOAD / 25 A PEAK LOAD
 - 15 A CHARGE TO TEMPERATURE COMPENSATED VOLTAGE LIMIT

NiH₂ Battery Reconditioning in LEO

9-CELL PACK TESTING

- RECONDITION PERFORMED FOLLOWING SEVERAL TEST CONDITIONS
 - 2.2 OHM TO 6.14V (AFTER TASKS 4A AND 4B)
 - 2.2 OHM TO 10.64V
10.2 OHM TO 6.14V (AFTER TASKS 4C AND 4D)

- MINIMUM EODV CHANGED FOLLOWING RECONDITIONING AFTER TASK 4C
 - IMPROVED VOLTAGE PERFORMANCE ATTRIBUTED TO REDISTRIBUTION OF ELECTROLYTE AND WATER IN CELL STACK DURING ONE WEEK OPEN CIRCUIT STAND FOLLOWING RECONDITIONING AFTER TASK 4C
 - FIGURE 1 SHOWS IMPROVEMENT IN EODV DURING CYCLING
 - FIGURE 2 SHOWS LESS EODV IMPROVEMENT WITHOUT OPEN CIRCUIT STAND FOLLOWING RECONDITIONING AFTER TASK 4D
 - FIGURE 3 SHOWS VOLTAGE PERFORMANCE DURING 15 A DISCHARGES

Figure 1. End of Discharge Voltage Comparisons

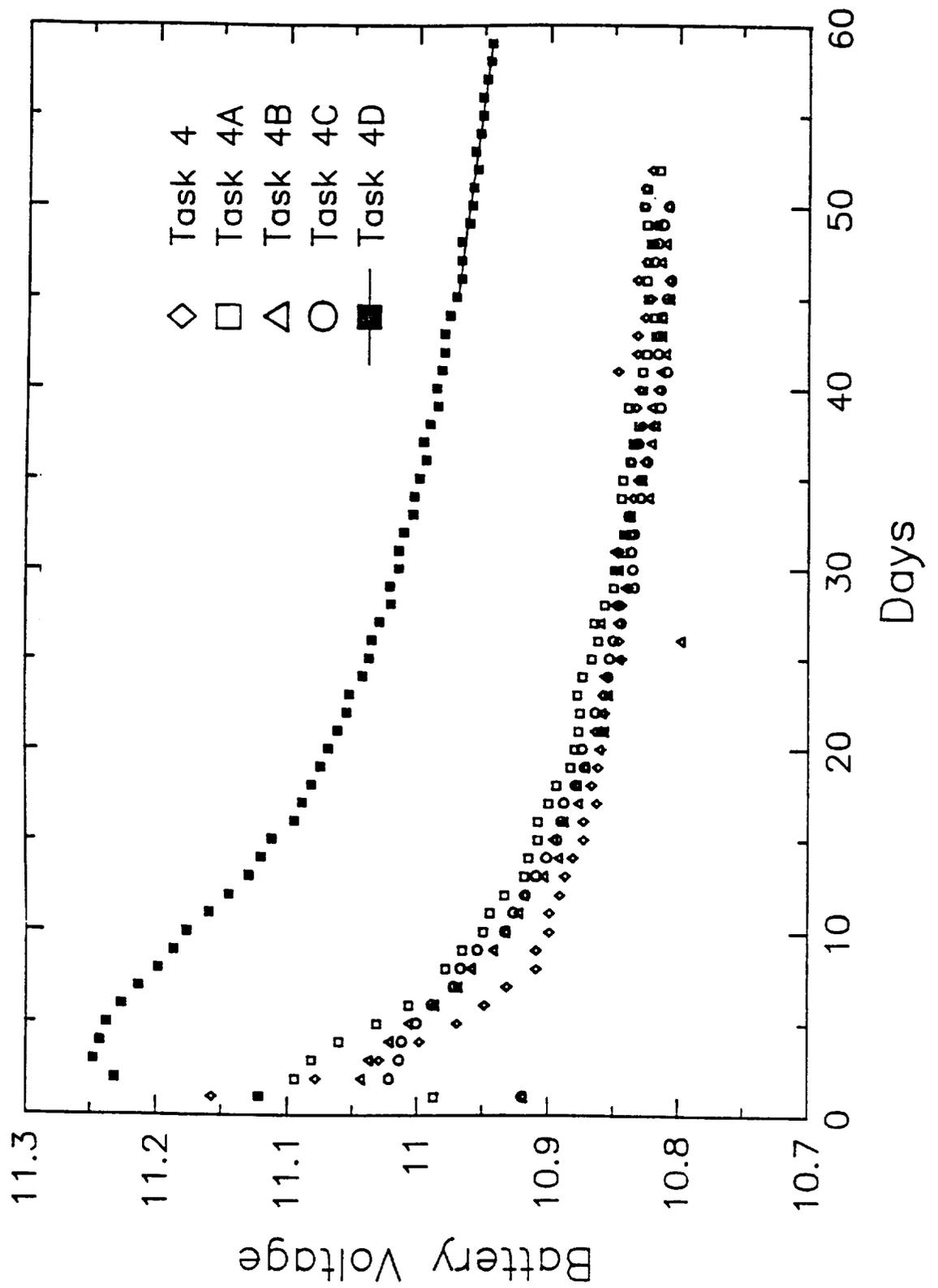


Figure 2. Comparison of Cycle 8 EODV after Reconditioning For Reconditionings D and D2

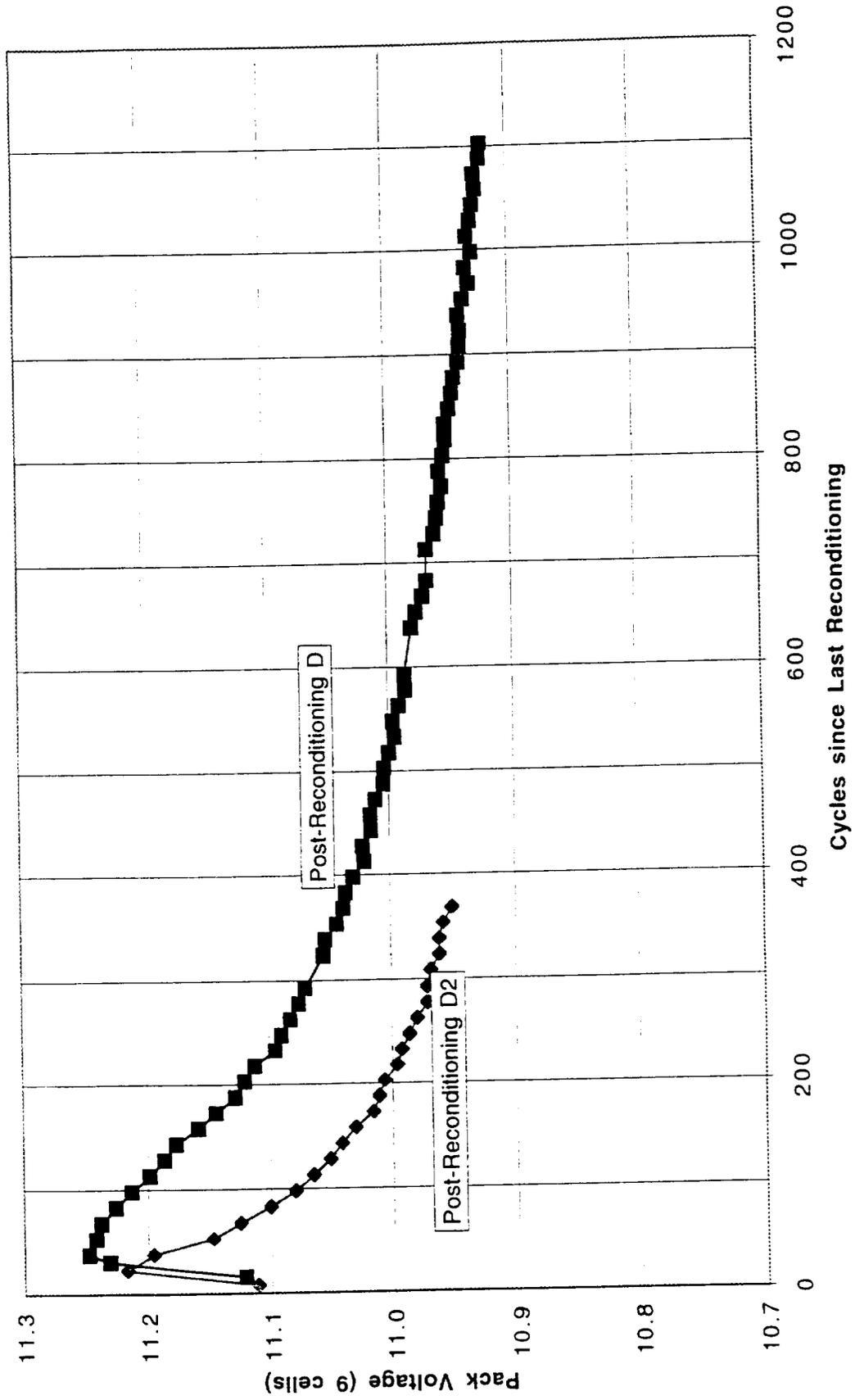
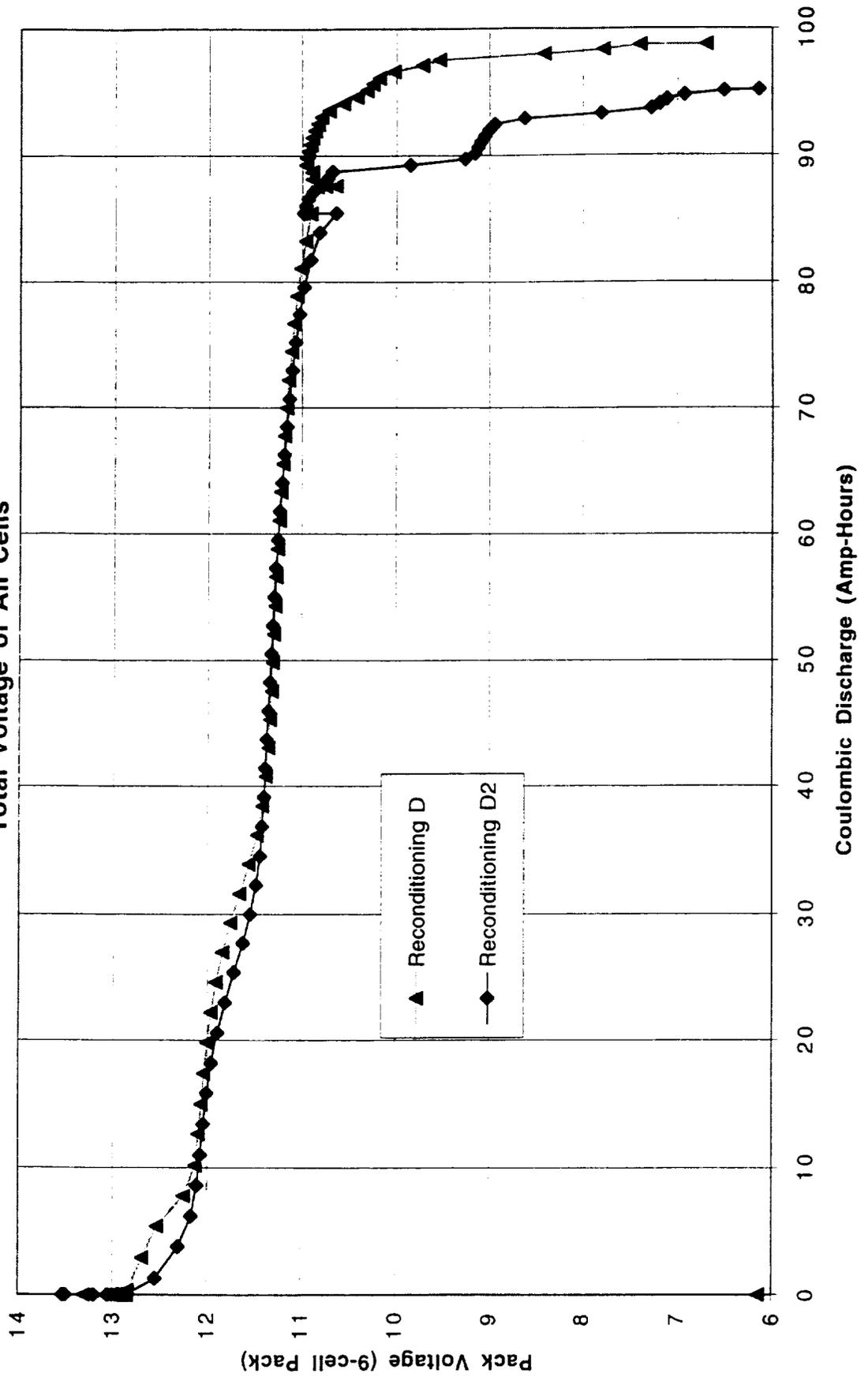


Figure 3. Nine Cell Test--Reconditioning D2
Total Voltage of All Cells



NiH₂ Battery Reconditioning in LEO

20-CELL BATTERY TESTING

- CAPACITY CHECKS OR PARTIAL RECONDITIONINGS IMPROVED MINIMUM EODV AS SHOWN IN FIGURE 4
 - CAPACITY MEASUREMENTS MADE AT 15 A RATE TO 13.6V OR FIRST CELL TO 0.7V
 - PARTIAL RECONDITIONINGS DUE TO TEST EQUIPMENT PROBLEMS

- TREND IN DECREASING EODV WITH CYCLING OBSERVED
 - FIGURE 5 SHOWS VOLTAGE PERFORMANCE VERSUS CYCLES
 - TREND SIMILAR TO 9-CELL PACK DATA SHOWN IN FIGURE 1

Figure 4. Qual Battery Performance

S/N -1005R, RNH76-3 Cells
20-cell configuration

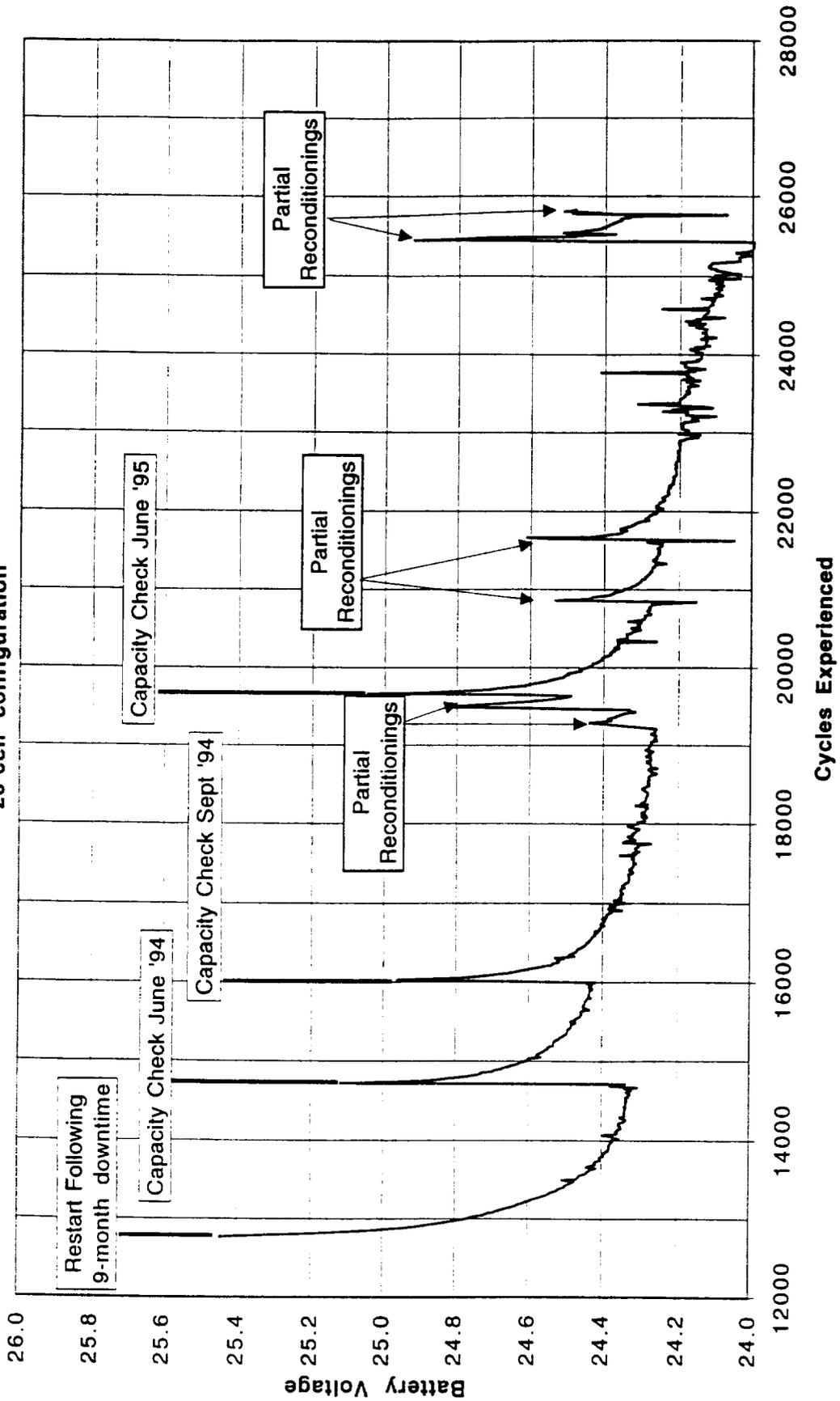
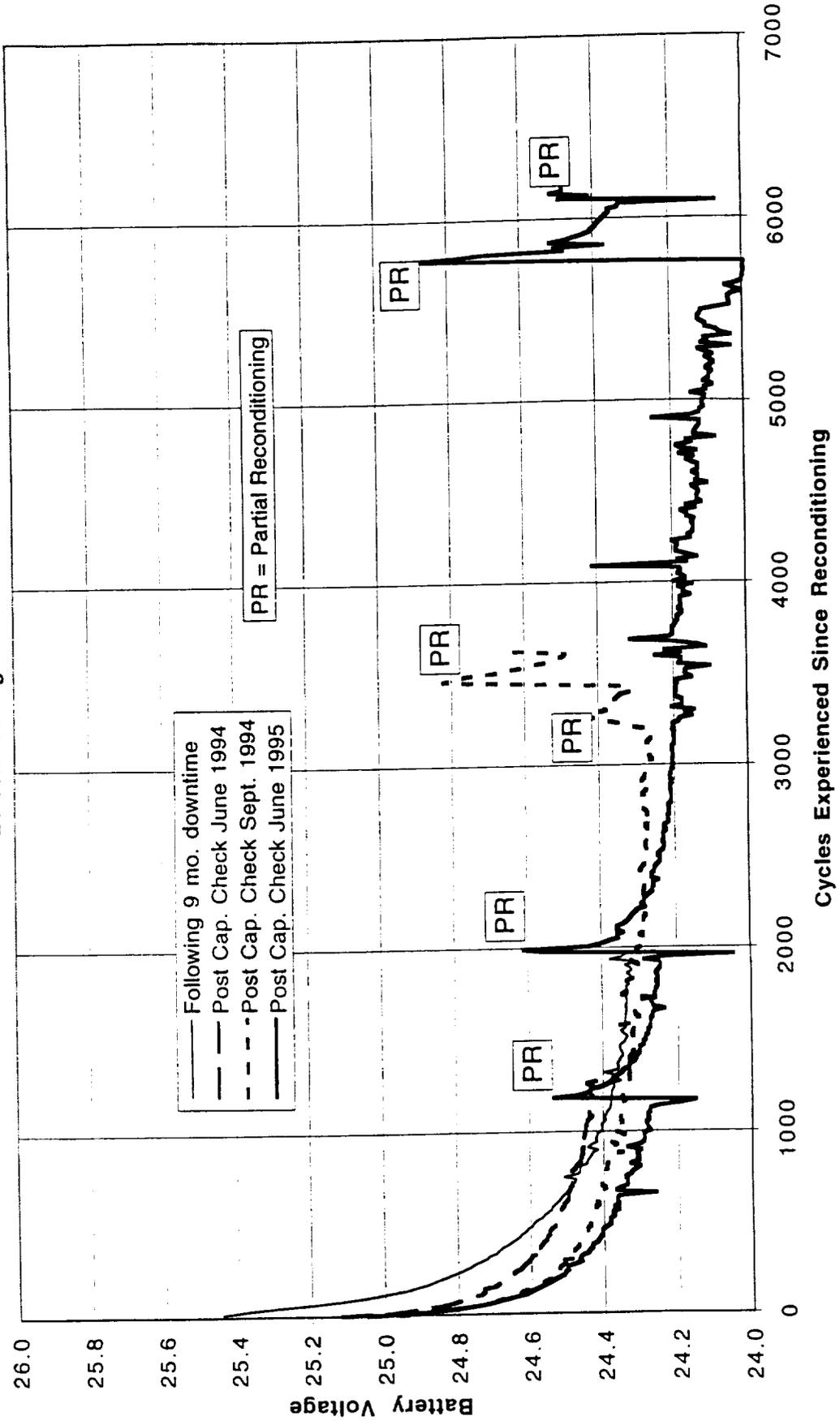


Figure 5. Qual Battery Performance

S/N -1005R, RNH76-3 Cells
20-cell configuration





NiH₂ Battery Reconditioning in LEO

CONCLUSIONS

- RECONDITIONING PROVIDES USABLE CAPACITY DATA FOR PERFORMANCE EVALUATION AND TREND ANALYSIS
- DEEP DISCHARGE BY WAY OF RECONDITIONING TENDS TO REDISTRIBUTE ELECTROLYTE AND WATER IN CELL STACKS
- RECONDITIONING RESTORES RESERVE CAPACITY LOST ON CYCLING AND IMPROVES VOLTAGE PERFORMANCE